# Zoning technique for a broadband fishnet metamaterial lens

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# Zoning Technique for a Broadband Fishnet Metamaterial Lens

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***Abstract*—The profile of any lens can be reduced by applying a zoning technique, at the expense of a narrower frequency range. Here, using an optimized zoning technique, a slim broadband zoned fishnet metamaterial lens with fractional bandwidth of 8.5% is designed, fabricated and measured at millimeter waves. Measurements are in good accordance with simulation results and demonstrate good performance of the zoned fishnet metamaterial lens. A high directivity of 16.6 dBi is experimentally achieved in the lens antenna system.**

## I. INTRODUCTION

THE control of light propagation continues to be one of the most popular research fields in electromagnetism. Historically this mission was entrusted to metals and natural dielectrics. However the use of conventional dielectrics to tailor the shape of electromagnetic waves is limited by the natural available permittivity and permeability values. Also their impedance mismatch and absorption losses make them less attractive for practical applications in the millimeter-wave and terahertz ranges. With the appearance of artificial dielectrics [1], and more recently metamaterials [2], researchers have gained more possibilities for designing classical beam shaping devices, such as lenses [3], beam steerers [4] and even cloaking devices [5]. The fishnet metamaterial is one of such promising metamaterials, which is suitable for microwave-to-terahertz frequencies, with low absorption losses, frequency-robust magnetic response and good impedance matching with air [6]–[8].

As a practical demonstration of its potential for millimeter-waves applications, fishnet-based lenses have been designed and experimentally analyzed at ~60 GHz [9]–[11]. Subsequently a zoning technique, well-known for centuries and used at the beginning primarily in optics [12], has been successfully applied for such metamaterial lenses [13]. It makes possible to reduce significantly the volume and, therefore, minimize losses and weight of the lens, at the cost of narrowing the frequency operation band.

Here we demonstrate that the frequency span of zoned fishnet lenses can be broadened without affecting their performance, by applying a smart combination of the zoning technique and lens profile optimization [14]. The designed and fabricated fishnet metamaterial was measured at two frequencies demonstrating a diffraction-limited ~$0.8\lambda_0$ transverse resolution for both foci. A lens antenna configuration showed directivity above 15 dB for both frequencies.

## II. RESULTS

The profile of the zoned fishnet metamaterial lens was obtained using an improved zoning technique, which exploits a strong dispersion of the fishnet and minimizes the root-mean-square-error between the smooth analytical profile and its staircase approximation (defined by the fishnet unit cell) for the whole band. The performance of the obtained optimized lens design was analyzed in lens and lens-antenna configurations. To this end, the zoned fishnet metamaterial lens was fabricated, measured, analytically and numerically studied at two frequencies, $f_1$ = 54 GHz and $f_2$ = 55.5 GHz.

Numerical and experimental results regarding the focusing performance are presented in Fig. 1. The experimental study showed a focal length of 48.5 mm and 51.5 mm for the first and second frequency, respectively, and a full width at half maximum of $0.7\lambda_1$ and $0.9\lambda_2$ for the first and second frequency respectively. All results demonstrate a good agreement with the design parameters.

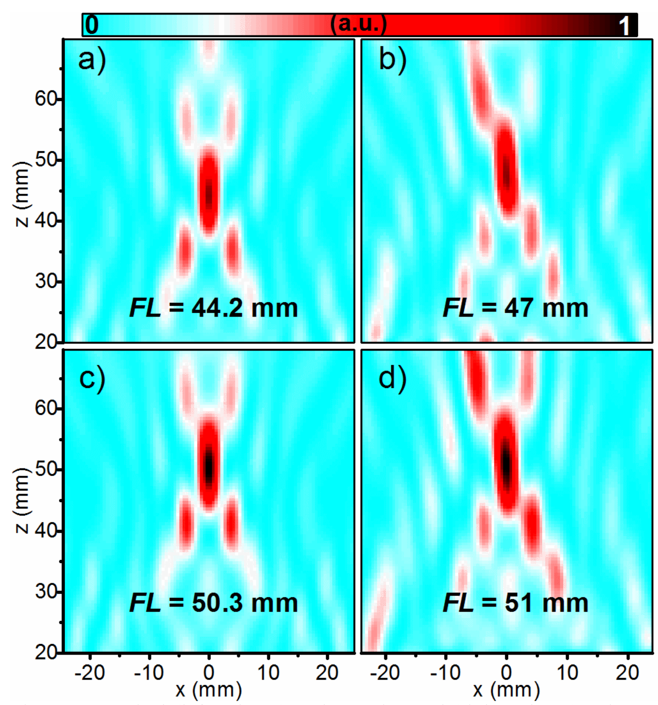


Fig. 1. Numerical (left column) and experimental (right column) color-maps for power distribution at *xz*-plane for $f_1$ = 54 GHz (a, b) and $f_2$ = 55.5 GHz (c, d).

In order to confirm the broadband performance of the designed lens, the maximum enhancement of 11.2 dB has been numerically obtained in the frequency range 52.5-58.25 GHz for this lens and a previously reported single-band zoned lenses [13] (See Fig. 2). The fractional bandwidth $FBW$ = 8.5% is confirmed for broadband zoned lens, where the enhancement is above the -3dB level (from the peak value). The single-band zoned lens presented in Ref. 8 achieved *FBW* = 4.9%.

With regard to the radiation performance in a lens antenna configuration, side lobes of 6.7 dB below the main lobe were found at ±7 deg for both frequencies. The beamwidth for the first and second band was 3.5 and 4.3 deg respectively. Both numerical and experimental results show directivities of the lens antenna above 15 dB for both frequencies in accordance with full-wave simulations.

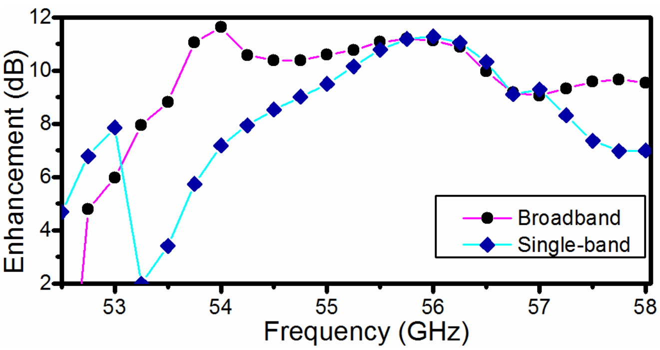

Fig. 2. Enhancement spectra for the improved broadband (pink line, circle symbol) and single-band designs (cyan line, rhombus symbol).

## III. Conclusions

A broadband zoned fishnet metamaterial lens has been designed, fabricated and measured at the V-band of millimeter-waves. The performance of the zoned lens has been analyzed numerically and verified experimentally, demonstrating broadband regime and good agreement with design parameters. The low-profile and weight of the zoned lens with millimeter-wave broadband response demonstrates a possibility to work in integrated systems with good performance compared to other conventional diffractive optical devices.

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